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ORIGINAL ARTICLE

Back to the future: Viewing a 1992 flood risk study through a 2017 lens

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Here we examine whether a study conducted 25 years ago (1992) would have had different conclusions if concepts and analytical methods developed since then had been used. The 1992 problem was to identify a strategy for reducing flood risk in the Netherlands by, for example, strengthening the river dikes against the risk of flooding. Since then, conditions related to flooding have been recognised as increasingly uncertain. In response, a new paradigm for strategic planning has emerged: the "adaptive planning approach," which aims to identify and assess strategies allowing for change, learning, and adaptation over time. We found that using the adaptive planning approach in 1992 would not have changed the main conclusions. But, it would have made explicit the need for the identification of vulnerabilities of the chosen strategy, a monitoring system to keep track of the uncertainties, and the possible actions to deal with the vulnerabilities that can be taken as the world evolves.

KEYWORDS
adaptive strategies, deep uncertainty, flood risks, retrospective analysis

1 | INTRODUCTION

1.1 | Background

1.1.1 | Situation in 1992

Over the period August–November 1992, the authors of this paper participated in a study for the Dutch Ministry of Transport, Public Works and Water Management on river dike strengthening in the non-tidal branches of the Rijn and Maas rivers. The impetus for the study was large-scale societal protests against river dike improvement projects, due to their harmful impact on the river's landscape and on the natural and cultural values in the surrounding areas. (We call these "LNC values". LNC is a Dutch acronym that stands for *Landschap, Natuur, en Cultuur*). While the primary purpose of a dike is to protect land from flooding, after a dike is built it assumes other values as well. Trees and other botanically valuable plants grow on dike slopes. People build houses on the dikes, which come to have historical or scenic significance. A dike curving through the landscape may be viewed as a valuable part of the Dutch scenery. So, the objective of the study was to identify a strategy that would provide a high level of safety, would not cost too much, and would preserve as much as possible of the existing LNC values along the rivers.

1.1.2 | Situation now (2017)

Much has changed in the 25 years since the end of the study. Perhaps most important, in the Netherlands it has increasingly been recognised that flood risk strategies that neglect uncertainty may go wrong, because there is so much uncertainty about how the future may evolve. For example, evidence has been building that the earth is undergoing global climate change, which is causing changes in rainfall, storm

*This paper is unrelated to O. van de Riet's current affiliation. Instead, the paper is based on her work at RAND Europe, where she was previously employed.

intensities, and river flows. And there are other major uncertainties, such as demographic change and economic development. In fact, in 2007 the Dutch Government established a Commission for identifying actions to reduce flood risk, since flood risk has increased in the past and will increase in the future due to the expected future climate change and economic growth (Deltacommissie, 2008, p. 5).

The situation being faced has been referred to as "decisionmaking under deep uncertainty," where deep uncertainty is defined as "the condition in which analysts do not know or the parties to a decision cannot agree upon (a) the appropriate models to describe interactions among a system's variables, (b) the probability distributions to represent uncertainty about key parameters in the models, and/or (c) how to value the desirability of alternative outcomes" (Lempert, Popper, & Bankes, 2003).

Under deep uncertainty, traditional predictive planning approaches that produce a static "optimal" plan for an assumed future scenario are problematic, since such plans may perform well under "most likely" or average conditions, but they may be ineffective or counter-productive under different conditions. Moreover, as the future unfolds planners can learn and respond to the new situation by adapting the plans to improve their performance. This response may, in turn, influence the environment. Modification of the plan over the course of time is not only determined by what is known or anticipated at present, but also by what will be experienced and learned as the future unfolds (Yohe, 1990), and by the policy responses to events (Haasnoot, Middelkoop, Offermans, Van Beek, & Van Deursen, 2012). Thus, the planning process becomes part of the storyline, and thereby an essential component of the total uncertainty.

A new and widely adopted approach for decisionmaking under deep uncertainty has emerged: the "adaptive planning" approach (Haasnoot, Middelkoop, Van Beek, & Van Deursen, 2011; Hallegatte, 2009; Lempert et al., 2003; Schwartz & Trigeorgis, 2004; Swanson et al., 2010; Walker, Haasnoot, & Kwakkel, 2013; Walker, Rahman, & Cave, 2001). Central to this approach is the identification, prior to the plan's implementation, of the plan's vulnerabilities (what could happen that would cause it to fail). This would include a systematic review of possible actions to take in advance to prevent it from failing, and actions to take later, as the vulnerabilities appear. The adaptive planning approach aims to identify and assess alternative strategies that—informed by new knowledge and changing circumstances—allow for change, learning, and adaptation over time.

This planning approach, in one form or another, has been receiving increasing attention in various policy domains. Dynamic flexible strategies are being developed for water management of New York (Rosenzweig et al., 2011; Yohe & Leichenko, 2010), New Zealand (Lawrence & Manning, 2012), and the Rhine Delta (Delta Programme, 2011, 2012; Jeuken & Reeder, 2011; Roosjen, Van Der Brugge, Morselt, & Jeuken, 2012), and have been developed for the Thames Estuary (Lowe, Howard, & Pardaens, 2009; McGahey & Sayers, 2008; Reeder & Ranger, 2011; Sayers, Galloway, & Hall, 2012; Wilby & Keenan, 2012). Also in other fields such applications are arising (see Swanson & Bhadwal, 2009 and Walker, Marchau, & Swanson, 2010 for examples).

1.2 | Research questions

This paper addresses two questions:

1. Does the adaptive planning approach add something to the river dikes strengthening perspective of the 1992 study, and would it have resulted in different study conclusions?
2. What value does the adaptive planning approach bring for flood risk management planners compared to traditional approaches (e.g., Walker, 2000)?

The paper can also be viewed from a more general perspective. It is rare for the participants in a strategic planning study to take a retrospective look at the results of their study in terms of methodology: Would the study have led to different conclusions if the adaptive planning approach had been taken as the analytical method? What might have been done differently, given what we know now that we did not know then? The paper also tries to answer these questions.

2 | THE DUTCH CONTEXT (1992)

The country of the Netherlands would not exist without its flood defences (dunes, dikes, hydraulic structures). Without these defences, 60% of the Netherlands would be regularly or permanently flooded (Kok, Jongejan, Tanczos, & Nieuwjaar, 2017). Hence, safety is not of marginal interest, and for centuries independent waterboards have functioned with their own tax system to reduce the flood risk. In 1992, safety with respect to floods in the Netherlands was organised within dike rings, which are defined areas that will be flooded if a dike failure somewhere in the dike ring occurs (TAW, 1998). The dike rings, had a safety standard ranging from 1/10,000 per year (in coastal areas) to 1/1,250 per year (in riverine areas). Figure 1 shows the main dike rings in the Netherlands. The safety standard is the exceedance frequency of the design water level; the strength of the flood defence is designed in such a way that the dike can retain water levels that are lower than the design water level (TAW, 1998). In this paper, we focus on the 1992 situation. Moreover, we focus on the 1992 main decision problem of how to reduce flood risk in an uncertain future. Thus, we do not consider the method of calculating flood risk and its recent changes. In 1992, the design discharge was also reassessed, but this reassessment was not part of the main decision problem.

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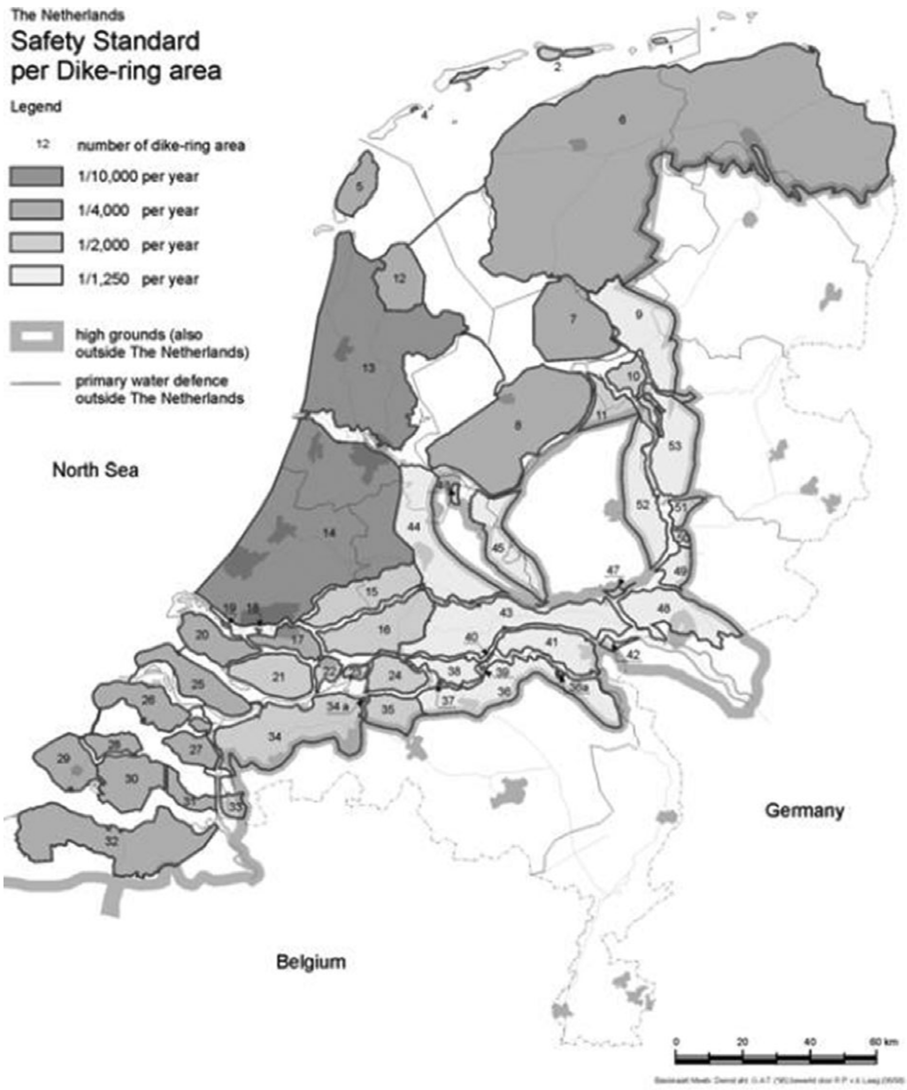

FIGURE 1 The main dike rings in the Netherlands (Netherlands Ministry of Justice, 1996)

Since flood defences deteriorate over time, safety assessments have to be carried out regularly (according to Dutch law, an assessment has to be carried out every 6 years). It was clear in 1992 that the river dikes did not meet the standards. The main questions were, therefore: do we have to revise the standards, or do we need new measures to increase safety to meet the existing standards? And, if we need measures, what kind of measures is most attractive? Around 1990, societal groups questioned the legitimacy of the reinforcement of the river dikes. There were large-scale societal protests against the river dikes improvement projects, due to their harmful impact on the river's landscape, and on the natural and cultural values in the surrounding areas (jointly, these were called LNC values). Even in Parliament, there were doubts about the reinforcement, and the Minister of Transport, Public Works, and Water Management installed a Commission (called the Boertien Commission, after its chairman) to advise the Minister about the reinforcement plans of the river dikes (Walker et al., 1994). This Commission initiated the study discussed in this paper—to provide the necessary knowledge input for the advice to the Minister.

3 | THE 1992 STUDY AND ITS AFTERMATH

3.1 | The 1992 study

The primary objective of the 1992 study was to identify a strategy that would provide a high level of safety, would not cost too much, and would preserve as much as possible of the existing LNC values along the rivers. The study focused on estimating the flood damage that would occur under alternative safety standards, estimating the financial costs of alternative dike improvement strategies, and estimating the damage that would be inflicted on the LNC values along the rivers under each of these strategies. For each strategy, the level of safety was measured in terms of flood damage. The cost had three components: (a) the cost of designing and planning for the construction, (b) the cost of actual construction, and (c) the cost of maintaining the dikes. The effect of a strategy on the LNC values was measured by the percentage of the existing LNC values that the strategy preserved. A detailed description of the study is given in (Walker et al., 1994).

The diverse consequences (or impacts) of the strategies examined were estimated by using a variety of models, and were displayed on *scorecards,*[1] which provided a common framework for comparing the strategies. The scorecards were used to show the trade-offs among the three types of impacts: the financial costs of implementing a strategy, the benefits in terms of flood damage protection resulting from a strategy, and the LNC values preserved by a strategy. The first two impacts were expressed in monetary terms; the last was an estimate of the percentage of the existing LNC values that would be preserved by a given strategy.

We examined several strategies. A flood protection strategy in the 1992 study had two components: a safety level, and a design for improving the dikes and/or reducing the water level of the rivers to provide the chosen level of safety. For ease of presentation, separate scorecards were prepared to present comparisons for each of the two strategy components (a safety level scorecard and a dike design scorecard [see Walker et al., 1994]).

The strategies in the study were investigated in a two-step approach:

1. *Screening*: all possible and meaningful measures (single changes) were given a quick examination in order to identify those that were promising.
2. *Strategy design*: the promising measures were combined into several alternative strategies.

In the screening phase, many possibilities for improving the safety along the rivers were investigated, including several measures in a category called "Room for the River." The most promising of these measures was lowering the water levels by lowering the floodplains, which reduce water levels by 0.6–1.1 m (a substantial amount). However, these reductions of water levels would only reduce the length of needed dike improvements from 372 to 342 km. The reason for such a small reduction is that the heights of the dikes was not so much of a problem, but the strength of the dikes was much more of a problem. It was also concluded that implementation of "Room for the River" measures would take more than several decades, and rapid implementation would disturb the clay and sand markets. Moreover, it would not solve the 1992 decision problem. So we decided not to consider any of these measures.

Table 1 presents the flood protection strategies considered in the study (after the screening step). We gave the name "smart dike design" to constructions that enable dikes to provide the same level of safety as "standard dikes," but that have less impact on the LNC values around the dikes. Examples of "smart dike designs" are filter constructions, coffer dams, and the use of sheet piles. These designs reduce the damage to LNC, since they need less space than standard designed dikes. Three smart dike design strategies were developed. The first strategy ("Improved current") applies smart designs only to "bottleneck" sections of the dikes. This is more costly than standard dikes, but has only limited effect on the preservation of LNC values. The second strategy ("Very smart") preserves as much of the LNC values as possible, but is very costly. The third strategy ("Selective smart") eliminates the most expensive smart designs from the second strategy, producing more damage to LNC values, but at significantly lower cost.

TABLE 1 The flood protection strategies considered in the 1992 study

	Safety level		
Dike design	**1/200**	**1/500**	**1/1250**
Current design	x	x	X
Improved current			X
Very smart			X
Selective smart			√

Note. x = the strategies considered; √ = the strategy chosen.

Flood risk is a function of the consequences of a flood and the flooding probability. Along the riverine area in the Netherlands, there is hardly any way to reduce the consequences, because the flooded areas can be completely filled with water to depths higher than 5 m. Lower safety (higher flooding probability) in the area was investigated in the study, but was considered to be unacceptable by the Commission because the number of potentially flooded people is huge in the protected area. Measures to increase safety (lower flooding probability) were not considered in the analysis, although this might have been attractive from a cost–benefit point of view. It was also investigated whether the use of lower safety levels for different regions was attractive (e.g., along the Veluwe—dike ring 52 in Figure 1). This possibility was discussed by the Commission, but was found to be unattractive, mainly because a lot of people would be flooded in case of a dike failure. Thus, the trade-offs focused on dike design.

The trade-offs among the three dike design strategies were examined using the three categories of criteria mentioned above: the financial costs of implementing the strategy, the benefits in terms of flood damage protection resulting from the strategy, and the LNC values preserved by the strategy. Scorecards were used to show the impacts of each of the strategies for the criteria in all three categories. The scorecards were also used in the debate in Parliament. The members of Parliament were very pleased with the study, and quickly made a choice of a preferred strategy (the strategy checked in Table 1). This strategy gave the opportunity to bridge the competing interests of the various stakeholders, since it would prevent half of the LNC damage, with only one-third extra implementation costs, and no reduction in safety. This provided a way to break through the political impasse. Six months after the project's completion, the Dutch Parliament approved a new strategy for the

[1]*Scorecards* are tables in which each column represents a strategy and each row represents an impact. An entire column shows all of the impacts of a single strategy; an entire row shows each strategy's value for a single impact. Numbers or words appear in each cell of the scorecard to convey whatever is known about the size and direction of the impact in absolute terms (Walker, 2000).

river dikes that was based on the study's results. Based on the scorecards produced by the project, the strategy advised by the Commission consisted of "selective smart" dike designs to provide a safety level of 1/1250 years.

3.2 | AFTER THE 1992 study

After the study (in 1995), a high discharge (with an estimated return period of 100 years) along the rivers Rhine and Meuse occurred, and 250,000 persons living along the river dikes were evacuated as a precaution. After this event, the debate about dike improvements ceased and the river dike improvement programme was accelerated. The "Deltaplan Big Rivers" was accepted in Parliament, a budget (about 800 million euro) was made available, and within 5 years all river dikes were improved to the 1/1250 standard. However, the 1995 discharge that had caused the floods led the Government to change the design discharge to 16,000 m^3/s from 15,000 m^3/s; hence, the (improved) dikes were not up to the (new) standard. A new "Room for the River" programme was launched to reduce water levels (by about 0.3 m) and to serve ecological objectives. This programme was finished in 2015, and had a budget of 2.3 billion euros. Examples of measures in the Room for the River programme are secondary channels and lowering floodplains (see Figure 2 for an overview of the measures being used).

Looking back on the 1992 study, there were some specific constraints and limitations. Most importantly, the study was focused on large-scale protests against proposed river dike improvement projects that would have a harmful impact on the LNC values—the focus was *not* on future changes in river discharges due to climate change. In those days, the likelihood and potential impacts of climate change were not as widely understood as they are today. For instance, data about the upper limit to the discharge of the Rhine river was not available, as it is now (Kok, Pol, & De Vriend, 2016). Also, uncertainties were handled with a semi-probabilistic approach, using design water levels and safety factors. Nowadays, a more probabilistic approach is followed with more diversity in safety standards (Kok et al., 2017), so uncertainties are taken into account more explicitly.

4 | THE ADAPTIVE PLANNING APPROACH

4.1 | Overview of the approach

The adaptive planning approach identifies vulnerabilities in a strategy design (i.e., future situations in which the objectives

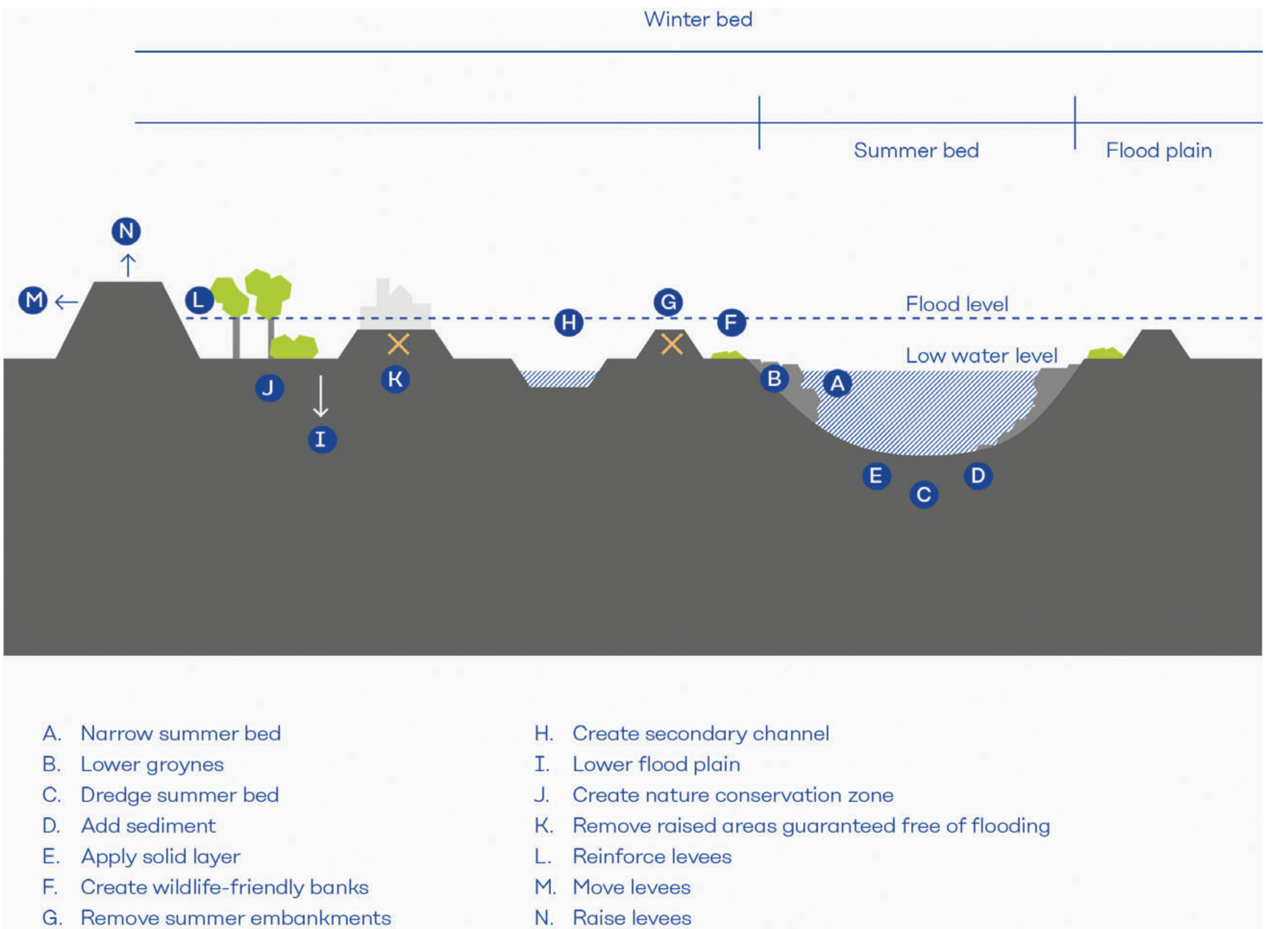

FIGURE 2 Overview of measures in the "room for the river" programme Kok, M., Jongejan, R., Tanczos, I., and Nieuwjaar, M. (2017)

would not be met) and strategy enhancements that—informed by new knowledge and changing circumstances—would allow for change, learning, and adaptation over time. The approach incorporates notions of scenario planning (van der Heijden, 1996), in which different plausible futures are explored, but goes beyond it by making use of flexibility concepts to deal with the vulnerabilities (de Neufville, 2000, 2003; Walker et al., 2001; Walker et al., 2013; Walker & Marchau, 2003). This flexibility can be needed to deal with the key uncertainties, because the future often turns out to be quite different from how any of the scenarios had envisioned it, which means that the (basic) strategy developed based on the scenario analysis can turn out to be inappropriate in the long run. Hence, it might be appropriate to build adaptivity into the basic strategy. A general value of the adaptive planning approach is that it can avoid (large) sunk costs in precautionary measures that may not be needed for some time or at all.

One operationalisation of the adaptive planning approach (van de Riet, Azami, & Van Rhee, 2008) consists of three steps:

1. *Identifying the vulnerabilities of the basic strategy* by identifying the key uncertainties: those factors that are both uncertain and have a major impact on the performance of the system, which can lead to failure of the strategy (i.e., the strategy failing to meet its objectives).
2. *Signposting and monitoring,* which involves determining the *trigger values* of the key uncertainties. When monitoring indicates that the trigger value of such a factor is reached, the policymakers are warned to reassess or adjust the strategy.
3. *Identifying possible ways to make the strategy adaptive,* in order to deal with the key uncertainties and prevent failure of the strategy when monitoring indicates the need to change it. This results in a list of possible actions to take now, and possible actions that can be taken as the world evolves. The possible actions are systematically reviewed based on their cost-effectiveness (It should be noted that the adaptive planning approach does not mean that investments with large initial costs are considered unattractive. These investments have to be traded off against other options).

Van Rhee, Pieters, and Van de Voort (2008) and van de Riet et al. (2008) provide good overviews of possible ways to make the basic strategy adaptive. These are summarised below.

1. *Shaping*. These are actions taken to reduce the chance that an external condition or event that could make the strategy fail will occur, or to increase the chance that an external condition or event that could make the strategy succeed will occur. Uncertainty can be shaped in three ways: by influencing the uncertainty, by investigating and learning (to decrease the knowledge gap), or by spreading the risk among actors (dividing the risk among the various actors, while taking into account which risk can best be carried out by which actor).
2. *Hedging*. To "hedge oneself" literally means "to protect oneself." This can be done by insuring (protecting oneself in the case of failure), by incorporating the option to exit (building into the strategy the possibility of abandoning the project), or by diversifying (spreading the risk over multiple factors that have no causal relationship with each other).
3. *Dynamic decisionmaking*. The basic idea behind dynamic decisionmaking is that decisions do not have to be made all at once, but rather can be spread over a period of time. This can be done by delaying decisions, by decelerating or accelerating projects, or by phasing a project.
4. *Flexible design*. A design can be made flexible by including the option to switch (e.g., by building in the flexibility of making the final technology choice at a later stage), the option to expand (e.g., by including spatial reservations), or the option to adjust the operational scale.

4.2 | An example showing the need for monitoring

It is important to note that the adaptive planning approach should be accompanied by a systematic monitoring system in which the measures are ready to implement when trigger values are reached. The importance of having these procedures in place and ready is illustrated by a case involving the bottom protection of the Netherlands' Eastern Scheldt storm surge barrier. Bottom protection is needed to protect the barrier from erosion of the area around the barrier. In the design, which was developed in the early 1980s, it was decided that bottom protection would be built only in the area 200 m next to the barrier. See Figure 3 for a schematic overview.

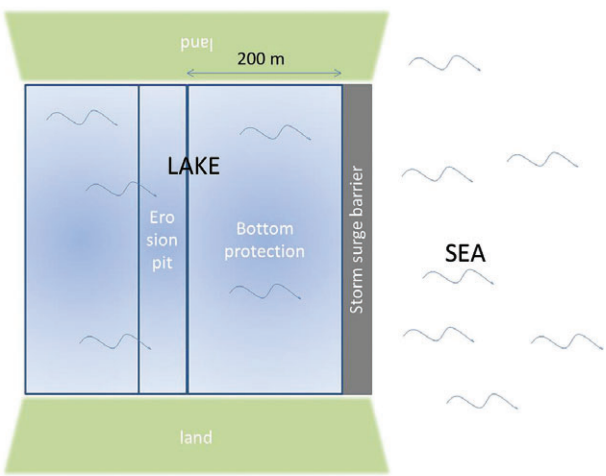

FIGURE 3 Schematic overview of the Eastern Scheldt Barrier

An erosion pit at the end of the bottom protection was considered, but it was concluded that monitoring and adaptation (if necessary) was the best approach. A monitoring mechanism was set up. However, in 2013 it was found that, although monitoring was taking place, the erosion process had reached an unacceptable level, and no action had been taken. The reason that no adaptive measures had been implemented was that there had been a loss of institutional knowledge within the responsible authorities (Spaargaren et al., 2013; see also Letter of the Minister of Infrastructure and the Environment to the House of Representatives, 2013). The responsible authorities had forgotten that the monitoring was linked to triggers and preplanned adaptive actions. The risks had reached an unacceptable level, and much more money was needed to repair the pits than would have had to be spent if the adaptive strategy had been followed.

5 | ADAPTIVE PLANNING FOR RIVER DIKE IMPROVEMENT

This section identifies the possibilities for an adaptive planning approach to river dike improvement—that is, ways the adaptive planning approach expands the scope of measures for consideration. Furthermore, it describes how we dealt with these measures in 1992, and what happened later.

5.1 | Identify key uncertainties

The first step in the adaptive planning approach is the *identification of the vulnerabilities of the strategy by identifying the key uncertainties* (those factors that are both uncertain and have a major impact on the functioning of the system, which can lead to the failure of the strategy). One of the key uncertainties in river dike improvement is the expected extreme discharge. But there are also other important uncertainties, including the strength of the dikes, the changes in the river morphology, the acceptable risk (i.e., the risk that society finds acceptable), and the flood damage and casualties in case of a flood. The 1992 study focused on the (future) river discharge, the acceptable risk, and the state-of-the-art knowledge on how to translate the acceptable risk into a design discharge. Nowadays, it is more common to also include the strength of the dikes (see, e.g., Jongejan et al., 2013). In addition, there is more information on the consequences of flooding.

5.2 | Monitoring and trigger values

The second step in the adaptive planning approach is *signposting and monitoring*. Signposting is determining the trigger values of the key uncertainties, which function as warnings for policymakers to reassess or adjust the strategy.

5.3 | Identification of options

The final step is the identification of *ways to bring in adaptivity* in order to deal with the key uncertainties and prevent the strategy from failing. We discuss these adaptivity options below.

5.3.1 | Shaping options

Option 1a. Shaping by influencing uncertainty.

One way to reduce the (design) discharge uncertainty would be to set up agreements with Germany and Belgium, the countries neighbouring the Netherlands. The main rivers passing through the Netherlands come from these countries. Since land use (e.g., the amount of surface that is covered with asphalt) affects the water discharge to the rivers, building activities in the neighbouring countries affects the design discharge in the Netherlands. *In 1992,* we studied the option of making agreements with the neighbouring countries. We screened out this option, because it did not solve the 1992 decision problem. However, the need for such arrangements has become more urgent as, *over time*, new knowledge has arisen. We now know that if the discharge is larger than 16,000 m^3/s (the design discharge in 2016), floods will occur in Germany. It is possible that additional water protection measures will be taken in Germany, which will have an impact on the design discharge. In fact, *after our study*, this situation was studied and the countries installed an international Rhine committee to share information about the Rhine river basin and the impact of river protection measures in the river basin. In fact, it is agreed that Germany will inform the Netherlands whenever it takes decisions that will influence the flooding probability in the Netherlands. So, later on, the countries agreed to inform each other about their flood protection strategy.

Another option to reduce the flood risk would be to create retention areas for controlled flooding. *In 1992,* we studied the option of retention areas, but screened it out because it did not solve the 1992 decision problem. However, in those days retention areas were seen as an alternative to dikes, not as an emergency measure to reduce flood damage. In 2002, a committee on Emergency Retention Areas advised the government to build retention areas, but the government rejected this idea, because its implementation would lead to only a small reduction in flood risk (see Kok et al., 2005). The reason for this is that the flood retention areas are very small relative to the river discharge, and bigger retention areas are not possible because the river area in the Netherlands is very densely populated. Hence, retention areas in order to reduce the need for dikes are not considered to be very helpful along the big rivers in the Netherlands.

A third option to influence risk from flooding would be to prevent people from living in areas that can be flooded. This option does not reduce the flooding probability, but it reduces the flood damage in case of a flood. *In 1992,* we did not consider this option explicitly. In *current* national water policy, it is not being considered.

Option 1b. Shaping by investigating and learning.

This option is about explicitly including research and pilots in future policymaking (e.g., on dike design and other flood protection measures; or on the design discharge itself, to study if it captures all elements of uncertainty). This option is always worth doing. However, *in 1992* we did not explicitly mention it, since the objective was to recommend a strategy that could be implemented without new research. *Meanwhile,* many pilots in innovative dike design have been carried out, and the results are now finding their way into implementation .

Option 1c. Shaping by spreading the risk among actors.

Public–private agreements among governments, companies, and citizens in the risk areas can be made in advance so that, if a flood happens, the burden is spread among a wide range of actors, including governments, companies, and citizens. These agreements often result in extra transaction costs. *In 1992,* we did not explicitly consider this option, since no one thought that this idea was attractive in the Dutch context. *Currently,* there is a law in the Netherlands saying that the government (i.e., the taxpayers) can partly compensate you if you suffer flood damage. However, a public–private agreement to spread the risk among actors goes one step further. In such a case, costs are spread among the actors whether or not your house gets flooded.

5.3.2 | Hedging options

Option 2a. Hedging by insuring.

This option is about setting up an insurance fund, so if a flood happens, the costs of the damage are reimbursed by the fund. *In 1992,* we studied the option, but screened it out for two reasons. First, the flood risk would remain much higher than the costs to reduce the risk, and more importantly, because of the accumulation of damages, insurance companies at that time were not interested to reduce it. *Meanwhile*, the insurance option has been restudied, but the outcome is not positive, since the cumulative damage is very large, resulting in high premiums for the citizens and companies, due to the low probability–high consequence nature of flood risk in the Netherlands (Autoriteit Consument & Markt, 2013).

Option 2b. Hedging by incorporating the option to exit.

Incorporating the option to exit can be realised by including an exit option in the design/implementation *process.* This could be done by starting the design process, while monitoring developments and changing the implementation pathway if a certain trigger value is reached (e.g., stop dike improvement activities if they do not make sense anymore). Of course, one can always quit. But by *explicitly* incorporating the option to exit, a conscious decision is made; and the monitoring system with the trigger values inserts alertness into the process. *In 1992*, we did not consider this measure, since it was an urgent problem to fix all dikes right away. *Currently*, this option is still not practiced.

Option 2c. Hedging by diversifying.

Diversifying can be realised by incorporating different types of measures, thereby creating a portfolio and diversifying the risk. *In 1992,* we considered the options primarily as either/or (e.g., dike strengthening OR floodplains), because combining the two was considered to be too expensive. *Currently*, additional measures (e.g., "Room for the River") are being implemented, which do reduce water levels and hence lower the height of flood defences These measures also serve ecological objectives.

5.3.3 | Dynamic decision making

Option 3. Dynamic decisionmaking by delaying, decelerating/accelerating, or phasing.

Dynamic decisionmaking could have been realised by starting with the most urgent dikes (the weakest parts of the system), continuing with research, and deciding what to do next. In addition, delaying or phasing enables changes in technology or society to be taken into account, and probably ends up providing better protection with lower costs. A prerequisite for this is monitoring of the dikes, the river, and societal preferences (the vulnerabilities and associated key uncertainties), and defining trigger values (which is step 2 of the adaptive planning approach). *In 1992,* we did not consider this option, since it was an urgent problem to fix all dikes right away. *Currently,* this option is part of the planning process, which is facilitated by risk assessment tools that are currently available to assess the actual dike strength (Jongejan & Maaskant, 2013).

5.3.4 | Flexible design options

Option 4a. Flexible design by including the option to switch to other functions

Switching could be realised by building multi-functional flood defences, that is, flood defences that can fulfil other functions as well. For example, a dike could be built in such a way that it would be able to fulfil a transport function as well (in this case, a wide dike stretch might be preferred), or a recreational/nature function (in this case, a curved dike design might be preferred), or both (in this case, the foundation should be strong enough). *In 1992,* we did not study this option, since combining the flood protection function with roads and sheep was common practice; other functions (such as housing) were not considered acceptable in those days, since they were considered to undermine the flood protection function. *Currently*, multi-functional flood defences are becoming increasingly accepted.

Option 4b. Flexible design by including the option to expand.

Including the option to expand could be realised by building the dike in such a way that it can be easily strengthened or heightened (e.g., by making spatial reservations, or by improving the dikes in a different way). *In 1992*, this option was not part of our analysis, because we considered it to be an implementation issue. *Currently*, it is common practice.

Option 4c. Flexible design by adjusting the operational scale

For conventional dikes this option is irrelevant, since there is no way to change the operational scale of a conventional dike. For smart dike designs, such as barriers that can be opened and closed (e.g., as applied in the cities of Kampen and Venlo), this option can be implemented on a local scale. *In 1992*, this option was not part of our analysis, because we considered it to be an implementation issue.

TABLE 2 Ways the adaptive planning approach expands the scope of measures for consideration, how we dealt with these measures in 1992, and what happened later on

Adaptivity option	Possible measures for the river dikes case	Way we dealt with these measures in the 1992 study	Measures studied later on?
Option 1a. Shaping by influencing uncertainty	Set up agreements with Germany and Belgium, the countries neighbouring the Netherlands	We studied this measure, but screened it out, because it did not solve the 1992 decision problem	Studied later on; the countries agreed to inform each other about their flood protection strategy
	Create retention areas for controlled flooding	We studied this measure, but screened it out because it did not solve the 1992 decision problem	Studied later on, but rejected
	Prevent people from living in areas that can be flooded	We did not consider this measure explicitly	Not considered to be a realistic option in current national water policy
Option 1b. Shaping by investigating and learning	Explicitly include research and pilots in future policymaking (e.g., on dike design and other flood protection measures; or on the design discharge itself, to study if it captures all elements of uncertainty)	We did not explicitly mention this option, as the objective was to recommend a strategy that could be implemented without new research	Many pilots in innovative dike design have been carried out, and the results are now finding their way into implementation
Option 1c. Shaping by spreading the risk among actors	Make public–private agreements in advance, so that, if a flood happens, the burden is spread among a wide range of actors, including governments, companies, and citizens	We did not consider this measure explicitly, as no one thought that this idea was attractive in the Dutch context	Partly applied. There is a law in the Netherlands saying that the government can partly compensate you in case you suffer from flood damage. However, this option goes one step further costs are spread among the actors whether or not your house gets flooded
Option 2a. Hedging by insuring	Set up an insurance fund	We studied this measure, but screened it out, as it does not reduce the risk of flooding	Insurance has been restudied, but the outcome is not positive, as the cumulative damage is too large
Option 2b. Hedging by incorporating the option to exit	Include an exit option in the design and implementation *process*	We did not consider this measure, as it was an urgent problem to fix all dikes right away	Still not practiced
Option 2c. Hedging by diversifying	Incorporate different types of measures, thereby creating a portfolio and diversifying the risk	We did not consider this measure explicitly, because we considered the options primarily as either/or, because combining different options was considered to be too expensive	Additional measures (e.g., "room for the river") are now taken into account, which do reduce water levels. These measures also serve ecological objectives
Option 3. Dynamic decision-making by delaying, decelerating/ accelerating, or phasing	Start with the most urgent dikes, continue with research, and decide what to do next, taking technological and societal developments into account	We did not consider this measure, as it was an urgent problem to fix all dikes right away	Now part of the current planning process, which is facilitated by new risk assessment tools that are currently available to assess the actual dike strength
Option 4a. Flexible design by including the option to switch to other functions	Switching could be realised by building multi-functional flood defences	We did not consider this measure, because multi-functional flood defences were (apart from additional road and sheep functions) not considered acceptable, as in those days other functions (e.g., housing) were considered to undermine the flood protection function	Multi-functional flood defences are becoming increasingly accepted
Option 4b. Flexible design by including the option to expand	Build the dike in such a way that it can be easily strengthened or heightened (e.g., by making spatial reservations, or by improving the dikes in a different way)	We did not study this measure because we considered it to be an implementation issue	Common practice
Option 4c. Flexible design by adjusting the operational scale	This option appears to be irrelevant for conventional dikes. For smart dikes, this option can be implemented	We did not consider this measure because we considered it to be an implementation issue	Sometimes practiced, for example, in the cities of Kampen and Venlo

5.4 | Summary for 1992 and now (2017)

Columns 1–3 of Table 2 summarise the results described above. Column 4 indicates whether a measure was studied after 1992, and if so, what the result was. From the information in column 4, we can conclude that adaptivity options 2b, 3, 4b, and 4c are currently considered to be promising. Two other adaptivity options are still being studied: 1b and 4a.

6 | DISCUSSION

6.1 | Value of the adaptive planning approach

This section provides answers to the two questions posed at the beginning of this paper. The first question was "Does the adaptive planning approach add something to the river dikes strengthening perspective of the 1992 study, and would it have resulted in different study conclusions?"

From Table 2 in the previous section, we can see that the adaptive planning approach expands the scope of the measures that might be used in a strategy. The approach focuses much more on uncertainties than we did in the 1992 study. However, using the approach in 1992 would not have changed the main conclusions and recommendations.

6.2 | Answers to the research questions

As explained in the Introduction, the impetus for the 1992 study was large-scale societal protests against the river dike improvement projects, due to their harmful impact on the river's landscape and on the natural and cultural values in the surrounding areas. The objective of the 1992 study was to identify a strategy that would provide a high level of safety for the design life of the flood defences (50 years), and would not cost too much, but that also would preserve as much as possible of the existing LNC values along the rivers. The study achieved this objective by proposing a "smart dike design" strategy. This strategy gave the opportunity to bridge the conflicting interests, since half of the damage to the LNC could be prevented with only one-third extra implementation costs and without sacrificing safety. This appeared to be a way to break through the political impasse.

In the last decades, adaptivity concepts such as space reservation have been applied in practice (see column 4 of Table 2). In fact, the idea of adaptive planning has been adopted by the Netherlands in improving the river dikes: the Dutch Delta Programme, a programme that has been developed gradually over time, currently includes adaptive planning (Delta Programme, 2016) . Thus, over time, adaptivity ideas have been finding their way into the world, and would have been useful in our study if we were beginning it now. However, they would not have changed the main conclusions and recommendations of the study.

The second research question was "What value does the adaptive planning approach bring?" The approach brings in (a) a systematic assessment of the vulnerabilities in the river system, (b) a monitoring system to keep track of the uncertainties, and (c) a systematic review of possible actions to take now and possible actions that can be taken as the world evolves to deal with the vulnerabilities. It is always a good idea to review policies regularly. In general, the monitoring system should include early warning signals and adaptation signals (Haasnoot et al., 2015). An early warning signal gives an indication to start preparing the actions that may need to be taken, while an adaptation signal means that an adaptation tipping point (unacceptable performance of the system) is getting close, and the adaptive actions may soon need to be implemented. These signals need to be specified so that there is enough time to take the actions in time. It needs to be noted that sufficient time to respond is a prerequisite for the adaptive planning approach. If there is not enough time to respond (e.g., when an unexpected acute problem like a tsunami takes place), the approach would not work.

In general, policymakers are beginning to realise that, as part of the implementation of strategic plans, possibilities for their adaptation can be included. McCray, Oye, and Petersen (2010) have raised the question of whether practical means can be devised to keep policy yoked to an evolving knowledge base once decisions are put on the books. The adaptive planning approach is one way of doing this.

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